AIRBORNE COHERENT LIDAR FOR ADVANCED IN-FLIGHT MEASURMENTS
"ACLAIM"

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ACLAIM is a 2-micron lidar operating at 100 pulses per second using an 8 cm diameter expanded beam. It was developed for advanced turbulence detection with applications to supersonic inlet control, mitigation of aircraft gust response and aircrew / passenger warning for improved seatbelt utilization. CAMEX missions provide several significant test opportunities as outlined below.

OUTLINE SUMMARY:

DC-8 CAMEX Candidate Test Objectives for ACLAIM

ACLAIM and periscope installation experience and functional testing
ACLAIM 2-micron beta vs. signal range and CAMEX droplet measurements
Turbulence vs. DC-8 meteorological measuring system (MMS) gust time histories
Wind shear on climbs
Winds shear from ACLAIM and aircraft sensors vs. dropsondes
Wind shear and vertical velocity scan experiments, e.g. 3, 9, 15, 30, 45 deg views at an approximately constant airmass relative location
Flow instability in vicinity of clouds, jet streams etc.

ANNOTATED SUMMARY:

ACLAIM Applications, Flight Test Experiments and Characterization Tasks for Turbulence Detection, Mitigation and Meteorology (July 2001 update)

Forward Looking Turbulence Detection via ***velocity distribution in space.***
Line of sight parallels the flight path. 2-point (or multiple-point) structure function shows development of line-of-sight gust component differences due to turbulence and irregular shears
Time trend of range location in front of aircraft provides anticipation of encounter
Magnitude change with time at fixed air mass relative locations characterizes transient nature

Forward Looking Turbulence Detection via ***return pulse bandwidth increase***.
Line of sight parallels the flight path. Bandwidth vs. range shows location of turbulence

Time trend of range location in front of aircraft provides anticipation of encounter.

Lidar – Radar scanning ***line-of-sight comparisons (B757 only)***
For synchronous data with suitable backscatter for lidar and radar detection return signals; - compare locations and turbulence intensity indications. Also evaluate radial velocity component patterns and 3-D shear in the radial component field.

Transverse component estimation methods encompass several scanning patterns and algorithm concepts
On the DC-8 the ACLAIM periscope viewing line of sight (LOS) will be manually adjusted to different elevation angles to capture velocity changes along the LOS due to wind shear. One experiment will consist of timing the elevation angle changes to get LOS velocities from an altitude layer above the airplane from a sequence of elevation angles observing approximately the same airmass location (from two or more elevation angles) as it is approached by the airplane. A number of such observations both without airmass vertical motion and with vertical motion are desired.

Wind-shear experiments using *off-flight-path lines of sight-* to validate previous indications and assumptions for implicit relationships between wind shear and turbulence, e.g.
Lidar LOS at 5-20 degrees above flight path with altitude incremental resolution, along beam, better than 100m
Shear with altitude over 100m altitude increment vs. turbulence: LGT 1 m/s, MDT-SVR 2 m/s, and EXTRM 5 m/s
(These values assume no significant transverse component, but will need to be refined post flight)
Estimate shear vs. altitude approximately each 2 to 5 sec during selected data runs (post flight)
Change altitude, make repeat passes etc. to observe layer with a/c in & out of turbulence*

Shear layer change experiments
Check above behaviors up-, down- and cross-stream with respect to turbulence patch*
Seek wave-induced shear layer intensification and turbulence (JPL's microwave temperature profiler (MTP) data on CAMEX will assist greatly in identifying these areas)
Use repeat passes with flight track offsets and altitude steps to "map" shear and turbulence in baroclinic zones and other regions of forced instabilities * (Note; - the slope of shear layers and atmospheric thermal structures may range from 0.02 to 0.1 in, and near turbulence)

Atmospheric perturbation behavior characterization issues
Build correlation patterns between shear, frequency broadening, structure function, turbulence intensity and peak gust values as provided by post flight MMS data for CAMEX
Illustrate shear layer changes associated with thermal stability variations observed by CAMEX MTP
Examine thermal and shear structure changes up- and down- and cross-stream to the turbulence regions*

Explore relationships between the vorticity (wind shear sign, plane and altitude location, i.e. virtual vortex configuration) and the peak gust sign & gust reversal sequence experienced by the airplane

For turbulence events encountered, determine influences of thermal stability structures relative to the wind shear layer and flight path altitude

Mitigation – applications to feed-forward angle of attack estimation for aircraft control

CTI Scanning strategies for angle of attack estimation (B-757)

Basic 3 to 5 look-angle sequences (upward) on DC-8

Gust angle of attack reversal anticipation via advance vorticity indications (studies as noted above)

* Subject to sampling tracks used by CAMEX flight plans

TENTATIVE ACLAIM SAMPLING STRATEGIES

A variety of sampling strategies may be employed as a result of ACLAIM performance, atmospheric conditions and mission flight tracks. The application of ACLAIM as an advanced gust detection warning sensor in a primitive sense is the straight look ahead line of sight (LOS). Other scanning strategy concepts have been developed but not flight tested. A surveillance scan strategy would assist in avoidance as well as in detection-warning-buckle protection. In addition, the ability to look somewhat above or below the flight track can also assist in "seeing" nearby gust layers as well as in deriving an atmospheric vertical wind shear component which is expected to give additional inference of potential gust probability and intensity. When turbulence, gust eddies or other vertical motion oscillations are present on scales of a few hundred meters an appropriately increasing ACLAIM line-of-sight angle (LOSA) to view a fixed atmospheric relative position above the flight path may be used to derive a vertical motion component. Further description of ACLAIM data sampling categories follows below.

Clear air turbulence data acquisition:

<u>Straight look ahead</u> using LOSA within 2 degrees of the flight path angle (gamma) to the horizontal plane. A set of gust encounters in this mode may be analyzed for warning threshold, advance warning time, etc. with respect to the atmospheric relative approach and transit through the gust area.

<u>Inclined LOSA,</u> with respect to gamma, > 3 deg and flight track within 30 deg of the vertical wind shear vector. This mode will be used to detect the onset of critical wind shear values and their modification as a result of mixing dynamics in the turbulence patches. The upward LOSA will increase as the ACLAIM range (of valid LOS relative speed data) decreases. Increased LOSA will also be used to examine shear perturbations associated with smaller scale wave activity or other atmospheric discontinuities.

When LOSA >3 deg indicates turbulence likely, return to LOSA < 2 deg and track perturbation to encounter.

If neither LOSA > 3 deg or subsequent LOSA < 2 deg indicate incipient turbulence during a 20 sec watch, then increase LOSA to >10 deg and note / log any significant shear observations for inspection of attending MTP data.

<u>LOSA scan initiated by LOSA < 2 deg detection</u>. Use coordinated LOSA increase in steps to obtain data for estimations of *vertical motion* associated with forward view turbulence detection.

<u>LOSA scan initiated by LOSA > 3 deg detection</u>. (or 10 deg, TBD) Use coordinated LOSA increase in steps to obtain data for estimations of *vertical motion* associated with wind shear detection.

Cloud area data strategies:

Cloud approach. Maintain forward look LOSA < 2 deg for a few varied cases of cloud encounter. This mode is more likely to be sustained in cases where the cloud segment is expected to be short (judged by radar and prevailing cloud type).

Cloud top. When near the top of cloud (judged by view, radar, forecast or MTP data) Raise LOSA to >= 30 deg to search for returns not block by near-field opacity.

Vertical motion within cloud peripheral area. When approach opaque clouds at a range of > 15 km initiate an LOSA scan for vertical motion. Experiment with an array of cloud types.

1. ACLAIM Laser Characteristics

The ACLAIM and Air Force laser transceivers have the following nominal characteristics:

- Wavelength: 2.012 microns
- Pulse Energy: 10 mJ
- Pulse Repetition Frequency (PRF): 100 Hz
- Pulse Duration: 450+/-100 nsec
- Beam Diameter: 80 mm (transceiver exit beam)*
- Average Power: 1 W
- Beam Divergence: Focused at 2 km**

*Note: Beam divergence and diameter values are given at $1/e^2$ intensity points; transmit beam diameter is 5.66 cm as measured to 1/e intensity points

Flight Path Considerations

1. Steady level flight 30+ sec prior to, and after turbulence gives warning time / false alarm experience. Also allows evaluation of reference data from MTP, MMS & a/c winds
2. Separate passes through turbulence along up- down-wind vs. generally cross-wind tracks to investigate for any flow dependent warning accuracy factors, turbulence onset character etc.
3. Up/down-wind vs. cross-wind trajectories through turbulence also allow investigation of MTP perturbation pattern characteristics and MMS turbulence stationarity and isotropy
1. 4. Level, constant speed turns facilitate wind accuracy evaluation and wind-shear vector extraction from ACLAIM upward slanting L.O.S. data - - and would be helpful when turning in the vicinity of turbulence patches (>= one-third of opportunities would be appreciated)
4. If under-flying an ER-2 dropsonde area and wind shear layer, a flight track segment parallel to the wind shear vector is desired and/or the level constant speed constant altitude turn

ACLAIM Periscope and Splitter Plate

ACLAIM Lidar System Projecting Beam into Periscope